Rayon Flock: A New Cause of Respiratory Morbidity in a Card Processing Plant

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Background *Following employee respiratory concerns, we investigated the health effects of rayon flock exposure at a card manufacturing plant.*
Methods *We conducted a cross-sectional survey including environmental evaluation, standardized questionnaires, spirometry, carbon monoxide diffusing capacity testing, and methacholine challenge testing.*
Results *From a total of 239 participants, 146 (61%) reported working at least 1 hr per week in areas where flock-coated cards are processed ("flock workers") and 47 (20%) reported cleaning equipment with compressed air. These workers had generally higher prevalences of respiratory symptoms. Flock workers and employees with longer tenure at areas where flock-coated cards are processed were more likely to have restrictive impairment of lung function. Although dust and fiber samples were largely below the detection limits, peak exposures to airborne particulate occurred during cleaning with compressed air.*
Conclusions *Working with rayon flock and cleaning with compressed air were associated with health effects in workers at this plant.* Am. J. Ind. Med. 50:274–284, 2007.
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KEY WORDS: occupational diseases; interstitial lung diseases; cross-sectional studies; viscose fiber; flock workers' lung

INTRODUCTION

Workers exposed to flock-associated dust are at risk for a pathologically unique interstitial lung disease characterized by a lymphocytic bronchiolitis and peribronchiolitis with lymphoid hyperplasia [Boag et al., 1999; Eschenbacher et al., 1999]. Most flock is composed of synthetic fibers of about 1 mm in length, which have been cut from continuous filaments ("tow") of materials such as nylon, rayon, polyester, acrylic, or polypropylene. These short fibers are applied to adhesive-coated surfaces of many materials, such as fabrics and paper, to create a velvet-like finish on a variety of products, including upholstery coverings, greeting cards, glove boxes for automobiles, etc. The first clusters of flock workers' lung were identified in 1996, in association with nylon flock [Kern et al., 1997, 1998]. Polyethylene flock has been implicated in a case of flock workers' lung in Spain [Barroso et al., 2002], and polypropylene flock was associated with increased respiratory symptoms in Turkey [Atis et al., 2005]. This article constitutes the first investigation of the health effects of rayon flock exposure.

Employee respiratory concerns triggered an evaluation at a plant that manufactures greeting cards and ribbons. The manufacturing process includes ink printing at screen printers or offset printers; thermographic powder printing; application of flock or flitter (reflective polyethylene film glitter); die cutting, embossing, and/or foil application at

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small or large presses; page insertion; folding; counting; and packaging. Workers apply flock at conveyor lines by dispersing it in a flock machine onto adhesive-coated cards. Only rayon flock is used, but it is of multiple colors and two sizes (0.02 inches and 0.1 inches long; both 10–20 μm in diameter). Subsequently, cards coated with flock may go through other processes in the plant. To remove excess flock from cards, the plant locates card-cleaning modules and downdraft tables on the flock lines. Between production runs, workers blow remnant flock with compressed air from all equipment on the flock conveyor lines. This maintains uniform flock color for each card order. Compressed-air cleaning is also required at the other card-processing machines in the plant to prevent contamination on card orders as well as to remove flock and/or paper dust debris that can jam the machinery or interfere with optical detection components of the equipment.

METHODS

Environmental Survey

We observed bulk samples of flock by scanning electron microscopy (SEM) (Model S-570; Hitachi Instruments, Inc., San Jose, CA). In addition, a 2.5 g sample of the bulk flock material was agitated in a vibrating vial (Fisher Vortex Shaker; Scientific Industries, Inc., Bohemia, NY) and blown into a 20 L test chamber where a 10 mm nylon respirable dust sampling cyclone (MSA, Inc., Pittsburgh, PA) collected the airborne particulate at 1.7 L per minute on a polycarbonate filter, which was subsequently examined by SEM. Personal sampling included air samples for gravimetric concentration of respirable dust (NIOSH Method 0600) with side-by-side air samples for fiber concentration (NIOSH Method 7400 with A-counting rules) [NIOSH, 2003]. We used aerosol photometers (Personal Data RAM pDR-1000; MIE, Inc., Bedford, MA) to obtain real-time continuous relative levels of dust during some plant activities. To record events that might be associated with any observed peaks in real-time readings, we utilized video cameras during those measurements.

Population Survey

The study population for the cross-sectional medical survey consisted of 284 invited individuals of over 850 total employees at the plant. According to a priori assumptions regarding exposures, we invited all workers exposed to flock and paper dust ($n = 150$) and random samples of workers exposed to paper dust only ($n = 94$) and workers from the ribbon production areas (without significant flock or paper dust exposure) ($n = 40$).

After obtaining written informed consent, trained NIOSH interviewers administered a computer-based questionnaire to each participant [NIOSH, 2005]. It included sections on upper and lower respiratory symptoms, systemic symptoms, physician diagnosis of respiratory illnesses, smoking and work history, respirator use, and whether fit-testing had been conducted. Questions about lower respiratory symptoms were taken from standard, validated questionnaires [Ferris, 1978; National Center for Health Statistics (NCHS, 1994)].

Pulmonary Function Tests

Trained NIOSH technicians conducted spirometry testing, carbon monoxide diffusing capacity (DL_{CO}) testing, and either a bronchodilator test or a methacholine challenge test. Spirometry was performed using dry rolling-seal spirometers interfaced to dedicated computers, according to American Thoracic Society guidelines [ATS, 1995a]. Predicted values were calculated using published reference equations [Hankinson et al., 1999]. Participants with a forced expiratory volume in one second (FEV_1) greater than 70% of the predicted values performed methacholine challenge tests (MCT) [ATS, 2000]. The results of MCT were expressed as the interpolated concentration (mg/ml) of inhaled methacholine that caused a 20% fall in FEV_1 (PC_{20}). Measurements of DL_{CO} were performed using the single-breath technique in a Jaeger MasterScreen system [ATS, 1995b]. Predicted values for DL_{CO} were based on published prediction equations [Miller et al., 1983].

Data Analysis

To assess whether employees at this plant had excess symptoms and spirometry abnormalities, we compared participant results to national data from the Third National Health and Nutrition Examination Survey (NHANES III) [National Center for Health Statistics (NCHS, 1996)]. For these comparisons, we used indirect standardization for race (black, Hispanic, white), sex, age (17–39 years of age vs. 40–69 years of age), and cigarette smoking status (current, former, or never smoker). Sampling weights based on the NHANES III sample frame were used to calculate the expected prevalences of symptoms and spirometry abnormalities. We derived 95% confidence intervals (CI) using a method that assumes that the observed data are from a Poisson distribution [Kahn and Sempos, 1989]. The prevalences of symptoms were compared with respect to three ordinal categories of exposure: (a) workers without significant flock or paper dust exposures, (b) workers with only paper dust exposures, and (c) workers with both flock and paper dust exposures. When testing the associations of symptoms with these three categories we used the Mantel–Haenszel chi-square test for trend (i.e., linear association), which indicates whether increases in symptoms are associated with additional exposures. We modeled health outcomes in relation to flock-work, flock-tenure, cleaning with compressed air, and possible bivariate interactions between these factors or with the covariates. The initial models were assessed using stepwise selection or the C_p statistic [Mallows, 1973], along with examinations of collinearity, influence, and partial-regression plots. The covariates for the multivariate regression models and the logistic models included gender, race, height, body mass index (BMI), tenure, age, and smoking (pack-years). We used SAS software to perform statistical analyses [SAS Institute Inc, 2004], and chose a *P*-value of 0.05 for statistical significance.

RESULTS

Bulk Sampling

SEM images of the bulk flock material show the tendency for the rayon flock used at this plant to form shreds (Fig. 1). The airborne respirable particles collected in a test chamber after vibratory agitation of a bulk sample (Fig. 2) include many compact particles in addition to several elongated particles of various sizes, similar to photomicrographs of airborne samples collected at nylon flock plants [NIOSH, 2000a,b].

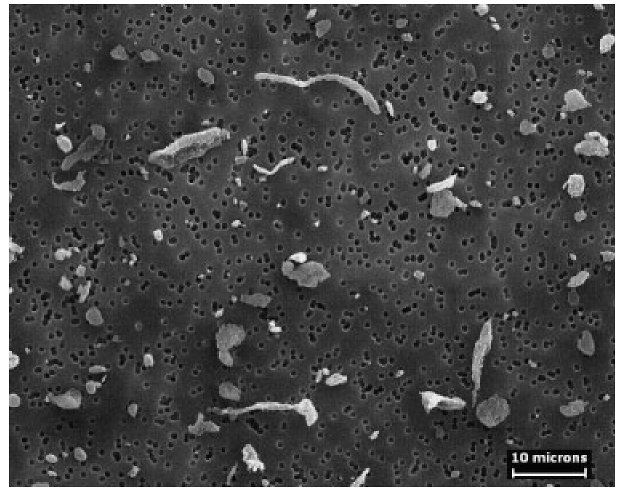

FIGURE 2. Scanning electron microscope image of airborne respirable dust sample collected in test chamber after agitating a bulk flock sample from a card manufacturing plant (2004).

Time-Integrated Sampling

We collected a total of 127 sets of full-shift personal samples (respirable dust and fibers). Only eight respirable dust samples had measurable concentrations, ranging from 0.03 to 0.06 mg/m^3. Measurable fiber concentrations were detected on 82 of the fiber samples, with 77 (94%) between 0.01 and 0.05 fibers per cubic centimeter (fibers/cc) and the remainder between 0.09 and 0.24 fibers/cc. No trend was apparent between measurable fiber concentrations and working with or around flocked cards; however, the highest concentration was measured on a worker who used compressed air to clean a flock line.

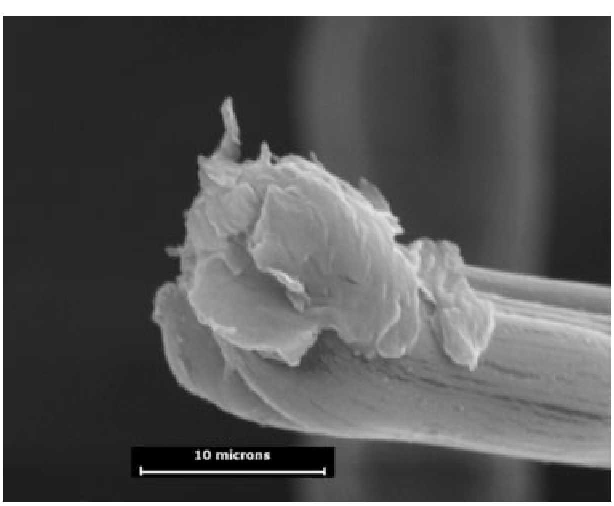

FIGURE 1. Scanning electron microscope image of the end of a flock fiber in bulk sample from a card manufacturing plant (2004).

Real-Time Sampling

Real-time personal and area air measurements obtained with aerosol photometer samplers (Fig. 3) show the relative response of the instrument to the airborne particles at different points in time. Measurements from the instrument worn by a worker while cleaning a flock module show elevated particle generation during cleaning compared to before and after cleaning. Peaks indicate that all cleaning activities are associated with increased airborne particulate, including vacuuming with a hose connected to a central vacuum system port. Based on review of the video, peaks appeared to occur when the worker reached into the flock module. One of the highest peaks was generated at the end of the cleaning activity when the worker blew the dust from his clothes with compressed air.

Study Population Demographics

Of the 284 workers initially invited to participate, 11 were absent due to sick leave or vacation, resulting in a total of 273 eligible employees during the 2-week survey. A total of 239 of these invited workers completed the questionnaire, resulting in an overall participation rate of 84% (of 284). The majority of employees were female (54%) and white (80%), reflecting the regional demographic distribution, and never-smokers (55%) (Table I). Nearly one-half of the employees had worked over 20 years at this

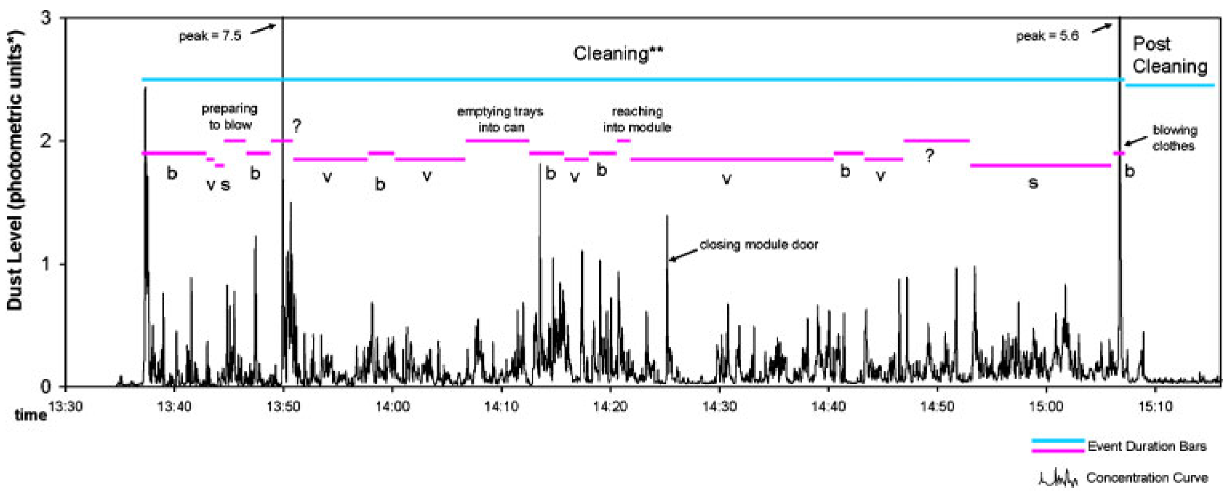

FIGURE 3. Real-time personal dust measurements during cleaning of flock module at a card manufacturing plant (2004). The bars represent the duration of activities during collection of the measurements, as obtained from the video tapes. b = blowing with compressed air; v = vacuuming; s = sweeping; ? = worker not visible in video of event (no blowing with compressed air heard). *Photometric units are the approximation of respirable dust concentration provided by the aerosol photometer. **Time-weighted average during cleaning = 0.17 photometric units. Simultaneous gravimetric time-weighted average was below 0.13 mg/m^3.

plant, and only about 12% had changed jobs within the previous year.

Work Practices and Respiratory Protection

The number of hours per week working with flock ranged from 0 to 54 (median = 5). A total of 146 participants (61%) reported working at least 1 hr per week in an area where flock-coated cards are processed, and thus were considered to be "flock workers" (Table II). The number of hours per week cleaning equipment with compressed air ranged from 0 to 15 (median = 0.3). A total of 47 participants (20%) reported cleaning equipment with compressed air for at least 1 hr per week. Of these, 35 were considered to be flock workers. The flock tenure (i.e., the number of years working

TABLE I. Demographics of the 239 Participating Workers at a Card Manufacturing Plant (2004)

	Flock and paper (N = 146)		Paper only (N = 59)		Ribbon (N = 33)		All participants (N = 239)	
Characteristic	**Number**	**% or [range]**	**Number**	**% or [range]**	**Number**	**% or [range]**	**Number**	**% or [range]**
Gender (female)	78	53	30	51	20	61	128	54
Race (white)	120	82	48	81	26	79	191	80
Age (median) [minimum-maximum]	45	[21–62]	46	[23–58]	45	[25–69]	45	[21–69]
Smoking status								
Never smoker	88	60	28	47	14	42	131	55
Former smoker	28	19	13	22	10	30	51	21
Current smoker	30	21	18	31	9	27	57	24
Tenure								
$\leq$5 years	17	12	5	8	2	6	23	10
5–10 years	24	16	8	14	6	18	39	16
10–20 years	37	25	12	20	14	42	63	26
>20 years	68	47	34	58	11	33	113	48
Change in job title in the last 12 months	23	16	3	5	2	6	28	12
Shift								
Day	59	40	28	47	20	61	107	45
Afternoon	50	34	26	44	13	39	90	38
Night	37	25	5	8	—	—	42	17

TABLE II. Frequency of Work in an Area Where Flock-Coated Cards are Processed and of Cleaning Equipment With Compressed Air, by Department, for the 239 Participating Workers at a Card Manufacturing Plant (2004)

	Participants in department	Work with flock $\geq$1 hr/week		Clean with compressed air $\geq$1 hr/week	
Department	**Number**	**Number**	**%**	**Number**	**%**
Foil stamp	66	58	88	18	27
Large die cut	43	20	47	5	12
Ribbon/bow	37	4	11	3	8
Manufacturing/finishing	34	13	39[a]	3	9
Counter packaging	35	27	77	7	20
Flock	14	14	100	8	57
Cardboard fold	10	10	100	3	30
Total	239	146	61	47	20

[a]Based on 33 workers (one worker was excluded due to not reporting hours of work with flock).

in areas where flock-coated cards are processed) among participants was longer than 10 years in 90 workers (38%), 3–10 years in 93 workers (39%), and shorter than 3 years in 55 workers (23%). One worker did not report flock tenure. Overall, 41 workers (17%) reported wearing air-purifying respirators. Use of respirators while cleaning equipment with compressed air was reported by 26 participants; none reported having been fit-tested.

Symptoms

Nasal irritation, sinus symptoms, and eye irritation were the most frequently reported symptoms. When we compared symptom prevalence of participating workers to national data, the ratios for ‘‘wheeze apart from cold’’ and for ‘‘shortness of breath’’ (i.e., dyspnea) were significantly elevated (Table III).

In general, flock workers had higher prevalences of symptoms arising during employment at this plant than non-flock workers with paper dust exposure and ribbon workers. Flock workers had similar prevalences of cough, phlegm, wheeze, wheeze attacks arising during employment, and pneumonia when compared to paper dust-exposed and ribbon workers. The prevalences of chest symptoms (e.g., cough, phlegm, wheezing, attacks of wheezing, or dyspnea) caused by specific materials at work, as well as eye, nasal, and

TABLE III. Ratios of Observed to Expected Number of Participants With Selected Symptoms and Spirometry Abnormalities in Comparison With NHANES III Data, Adjusted for Gender, Race, Age, and Smoking Categories at a Card Manufacturing Plant (2004)

Symptom/abnormality	N[a]	Observed number	Expected number	Ratio (95% CI)
Chronic cough[b]	230	29	21	1.4 (1.0–2.0)
Chronic phlegm[c]	230	25	17	1.5 (1.0–2.1)
Wheeze apart from cold[d]	230	54	27	2.0 (1.5–2.6)[h]
Dyspnea[e]	230	70	44	1.6 (1.3–2.0)[h]
Obstruction[f]	222	5	9	0.6 (0.3–1.4)
Restriction[g]	222	18	17	1.1 (0.7–1.7)

[a]Total number of workers with demographic characteristics comparable to NHANES data.
[b]Question 5c: “Do you usually cough like this on most days for 3 or more consecutive months during the year?”
[c]Question 6c: “Do you bring up phlegm like this on most days for 3 or more consecutive months during the year?”
[d]Question 7a: “Apart from when you have a cold, does your chest ever sound wheezy or whistling?”
[e]Question 10a: “Are you troubled by shortness of breath when hurrying on level ground or walking up a slight hill?”
[f]Forced expiratory volume in one second (FEV_1)/forced vital capacity (FVC) ratio (FEV_1/FVC%) $<$ lower limit of normal (LLN) and FVC $\geq$ LLN.
[g]FEV_1/FVC% $>$ LLN and FVC $<$ LLN.
[h]Statistically significant for $\alpha = 0.05$.

throat irritation, and sinus symptoms were higher for flock workers compared to paper workers and those of paper workers were higher than ribbon workers, with a statistically significant test for trend (Fig. 4).

Workers who cleaned for 1 hr or more per week using compressed air generally had higher symptom and diagnosis prevalences. The chi-square test was statistically significant for eye, nasal, and throat irritation, sinus symptoms, chronic cough, and medically diagnosed asthma (Fig. 5).

Pulmonary Function Tests

Spirometry test results were available for 234 workers (Table IV). Most cases of respiratory impairment were mild. Restriction was moderate in one worker and obstruction was moderate in one and severe in another employee. Of the 192 workers who underwent methacholine challenge testing, 10 had borderline bronchial hyperresponsiveness (PC_{20} in the range 4.1–16 mg/ml) and 5 had mild hyperresponsiveness (PC_{20} in the range 1.0–4.0 mg/ml). Of the 10 workers who underwent bronchodilator testing, two experienced an increase of at least 12% and 200 ml in FEV_1. Of the 231 workers who underwent DL_{CO} testing, one had a non-interpretable test, 9 (3.9%) had DL_{CO} below the lower limit of normal (LLN), and 33 (14%) had alveolar volume (V_A) below the LLN.

Analysis of Categorical Pulmonary Function Variables

No statistically significant association was observed between indices of flock exposure (i.e., current work with flock, flock tenure, and cleaning with compressed air) and spirometry results analyzed as categorical variables. However, employees with evidence of bronchial hyper-responsiveness ($PC_{20} \leq 16$ mg/ml) were somewhat more likely to have worked with flock for at least 1 hr per week, with an odds ratio of 4.2 (95% CI [0.9–19.1]). When bronchodilator response was analyzed together with

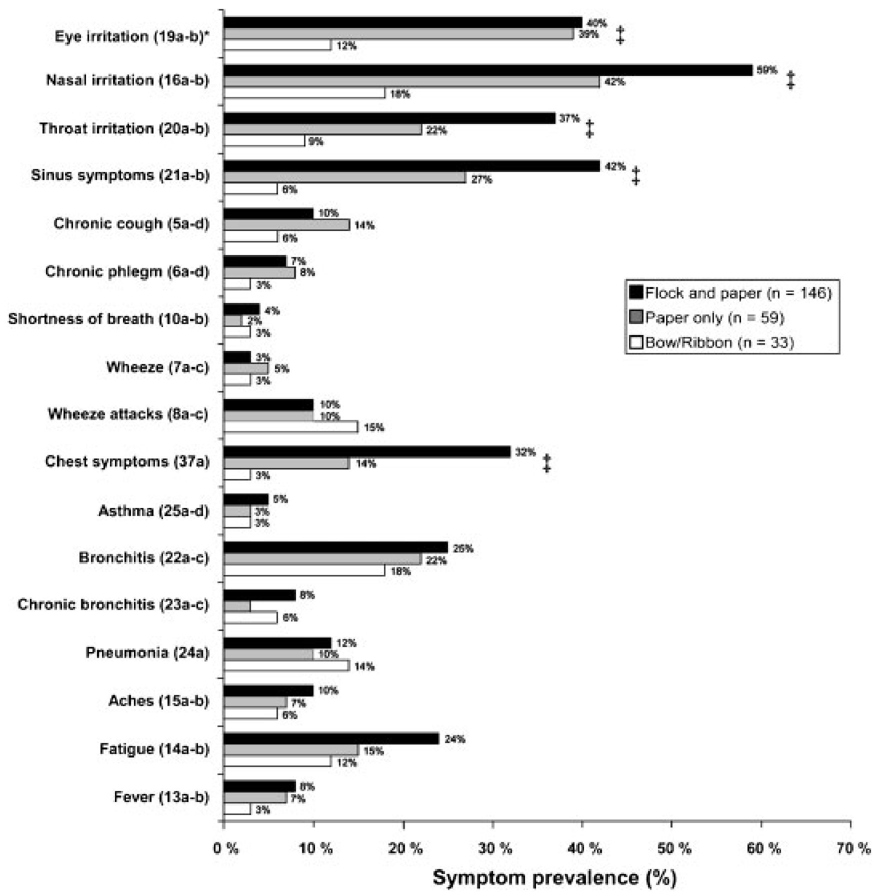

FIGURE 4. Prevalences of symptoms and self-reported physician diagnoses arising during employment among 238 participating workers†, by exposure group at a card manufacturing plant (2004). *The question numbers from the questionnaire [NIOSH, 2005], used to define each symptom, appear in parentheses. † One worker was excluded due to not reporting hours of work with flock. ‡ Chi-square for trend statistically significant for $\alpha = 0.01$.

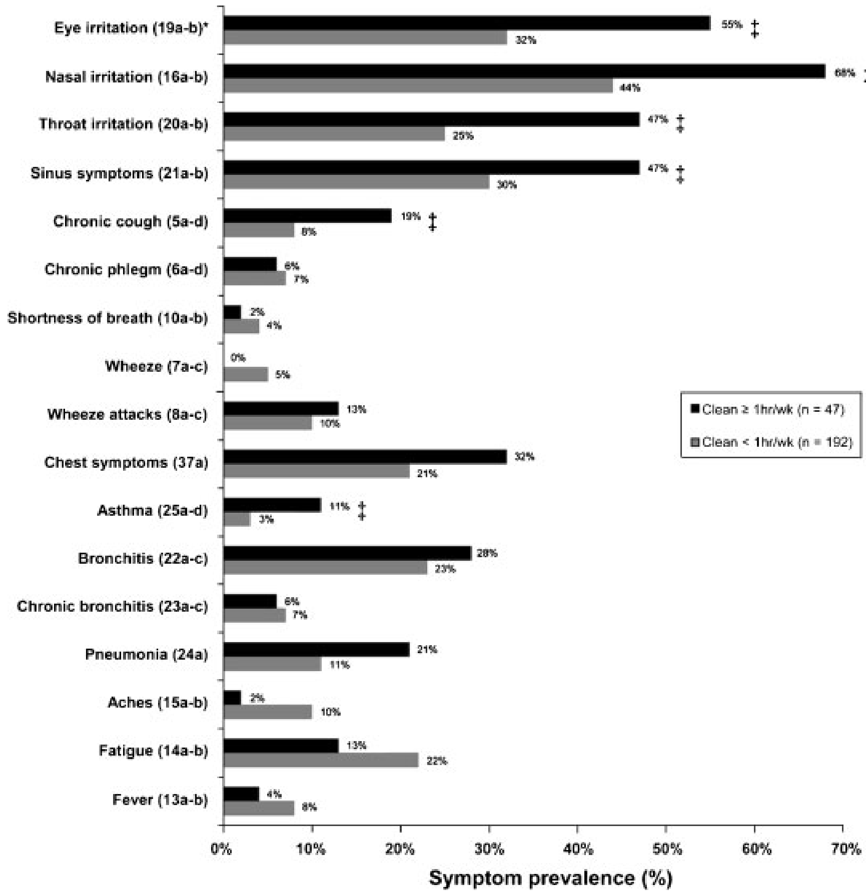

FIGURE 5. Prevalences of symptoms arising during employment, among 239 participating workers, by status of using compressed air for cleaning in a card manufacturing plant (2004). * The questions from the original questionnaire [NIOSH, 2005], used to define each symptom, appear in parentheses. ‡ Chi-square statistically significant for $\alpha = 0.05$.

TABLE IV. Spirometry Results and Patterns of Respiratory Impairment for 233* of 234 Participating Workers at a Card Manufacturing Plant (2004)

Variable	Flock and paper (N = 142)		Paper only (N = 58)		Ribbon (N = 33)		All participants (N = 233*)	
Spirometry results	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
FVC %	98.7	14.1	100.5	13.6	98.7	12.9	99.2	13.8
FEV_1 %	97.7	15.2	100.0	14.2	96.9	15.8	98.2	15.0
FEV_1/FVC	79.6	7.2	79.7	5.2	78.4	8.8	79.5	7.0
DL_{CO} %	94.8	13.3	96.3	16.3	95.9	12.3	95.3	14.0
V_A %	91.0	12.3	92.7	13.7	91.5	14.1	91.5	12.9
Spirometry pattern	Number		Number		Number		Number	
Normal	126		53		28		207	
Obstructive[a]	2		1		2		5	
Restrictive[b]	12		4		3		19	
Mixed[c]	2		0		0		2	

*One worker was excluded due to not reporting hours of work with flock.
[a]Forced expiratory volume in one second (FEV_1)/forced vital capacity (FVC) ratio (FEV_1/FVC%) < lower limit of normal (LLN) and FVC ≥ LLN.
[b]FEV_1/FVC% > LLN and FVC < LLN.
[c]FEV_1/FVC% < LLN and FVC < LLN.

methacholine challenge results, the trend persisted, with an odds ratio of 3.0 (95% CI [0.8–10.8]).

Multivariate Analysis

In multivariate models, working in areas where flock-coated cards are processed and cleaning equipment with compressed air were both significantly associated with the development of nasal symptoms after hire at this plant. Cleaning with compressed air was also significantly associated with the development of chronic cough. Models of other selected symptoms outcomes did not produce statistically significant results, for these indices of work exposures.

The results for the logistic model for nasal irritation with onset after starting work showed highly statistically significant effects for both cleaning with compressed air and flock work, with odds ratios (OR) of 2.6 (95%CI [1.5–4.5]) and 2.5 (95%CI [1.2–5.1]), respectively. The predicted probabilities suggest that non-flock workers who do not clean machines at least 1 hr per week have an estimated probability of approximately 30% of developing nasal symptoms. This probability increases to over 50% for workers if they were either flock workers or if they cleaned machines at least 1 hr per week. For those who both worked with flock and cleaned machines with compressed air at least 1 hr per week, the probability increases to about 75% (Table V).

The results for the logistic model for chronic cough also showed a statistically significant effect for cleaning (OR 2.6 (95% CI [1.0–6.5])). These results indicate that non-smoking workers who do not clean machines for at least 1 hr per week have an estimated probability of about 6% of developing chronic cough, and this rises to about 14% for non-smoking workers who cleaned machines at least 1 hr per week (Table V).

Longer flock tenure was significantly associated with abnormally low V_A and DL_{CO}, findings suggestive of interstitial lung disease. The predicted probabilities from the V_A model (OR 2.6 (95% CI [1.5–5.2])) suggest that a worker who is 45 years old with 20 years of tenure at this plant (i.e., the median age and tenure of participating workers), with a BMI of 30 (median = 29), and with zero years of flock tenure had an estimated probability of about 5% of having an abnormally low V_A. This probability increases to about 11% for a corresponding worker with 10 years of flock tenure, and to about 24% with 20 years of flock tenure (Table V). The predicted increases in abnormal DL_{CO} outcome with flock tenure are much smaller, and the small number of cases of workers with DL_{CO} below the LLN makes these results less reliable. The model suggests that a non-smoking worker had an estimated probability of about 1% of having a DL_{CO} below the LLN. The estimated probability increases to about 2% for a non-smoking worker with 10 years of flock tenure, and to about 4% with 20 years of flock tenure.

TABLE V. Cross-Tabulations of Frequencies (%) for Nasal Irritation, Chronic Cough (Both With Onset After Employment), and Alveolar Volume (V_A) Less Than the Lower Limit of Normal (LLN), by Exposure Indices and Covariates

	Health outcomes/covariates			
	Nasal irritation			
	Flock work <1 hr/week		**Flock work ≥1 hr/week**	
Exposure indices	**Nasal irritation**	**No nasal irritation**	**Nasal irritation**	**No nasal irritation**
Cleaning <1 hr/week	25 (31%)	56 (69%)	60 (54%)	51 (46%)
Cleaning ≥1 hr/week	6 (55%)	5 (45%)	26 (74%)	9 (26%)
	Chronic cough			
	Never-smokers		Ever-smokers	
	Cough	No cough	Cough	No cough
Cleaning <1 hr/week	5 (5%)	100 (95%)	11 (13%)	76 (87%)
Cleaning ≥1 hr/week	5 (19%)	21 (81%)	4 (19%)	17 (81%)
	Alveolar volume (V_A) < LLN			
	BMI[a] <30		BMI ≥30	
	V_A < LLN	Normal V_A	V_A < LLN	Normal V_A
Flock tenure <10 Years	5 (6%)	75 (94%)	9 (16%)	46 (84%)
Flock tenure ≥10 Years	5 (11%)	42 (89%)	14 (29%)	35 (71%)

Row percentages are shown for each two-by-two sub-table.
[a]Body mass index.

As mentioned in the methods, the model-building only considered bivariate interactions involving the covariates, but a further examination of the interaction effects for FEV1 and FVC outcomes indicated evidence of a three-way interaction between gender, pack-years, and flock work. In other words, the linear relationship between the outcomes and pack-years varied for different levels of gender and flock work. Although it should be noted that this resulted from post hoc comparisons, a further stratification of the results is more informative. The average adjusted FEV_1 and FVC values were both significantly lower for smoking male flock workers compared with smoking male non-flock workers (Table VI). No statistically significant differences were observed for females categorized by flock work, and no significant interactions existed between gender and cleaning or other potential explanatory variables. The mean FEV_1/FVC ratio was not statistically different for the exposure groups.

DISCUSSION

Despite levels of airborne flock-associated dust largely below the limit of detection using time-weighted averages, we found evidence of work-related health effects among employees at this plant using rayon flock. First, there was an excess of wheezing and dyspnea among participating employees compared to national rates. Within the plant, flock workers had increased prevalences of most symptoms compared to other workers. Employees using compressed air for cleaning, which was associated with high peak dust exposures, also had more symptoms than other employees. The symptom findings were corroborated by medical tests results. Specifically, current flock work or years of flock work were associated with trends toward airway hyperresponsiveness and gas exchange and alveolar volume abnormalities. In addition, current flock work was associated with decreased spirometry results among smoking male employees. In models that attempted to control for factors that contribute to nasal irritation and cough, flock work, and/or cleaning with compressed air remained significantly associated with these symptoms arising during employment.

The prevalence of work-related mucous membrane irritant symptoms (i.e., throat and eye irritation) was higher at this plant when compared with results of previous NIOSH investigations in plants where flock was produced/processed [Washko et al., 2000; Daroowalla et al., 2005]. In contrast, lower respiratory symptoms (i.e., dyspnea, cough, and wheeze) were reported less frequently among employees at this plant, which may in part be explained by the fact that dust and fiber levels at this factory are much lower than levels measured at the previously studied plants [Burkhart et al., 1999; Daroowalla et al., 2005].

The objective findings of low FVC, VA, and DL_{CO} are suggestive of a mild interstitial lung disease process (possibly flock workers' lung). Eschenbacher et al. [1999] reported that half of the cases of diagnosed flock workers' lung reviewed by an expert panel had a restrictive pattern, and in several other patients in the same group, TLC and FVC were in the low normal range. Almost 70% of these cases also had reduced DL_{CO}. In a nylon flock plant, restriction was observed in 7% of production workers compared to 3% in office workers; the prevalences of low diffusing capacity were 13% and 5%, respectively [Washko et al., 2000]. Among polypropylene flock workers in Turkey, 20% had restriction and 26% had low DL_{CO}, compared to 4.4% and 4.4%, respectively, of non-exposed controls [Atis et al., 2005]. The proportion of restriction among participants in this plant was 7.8%, and 3.9% had low DL_{CO}. The lower proportion of low DL_{CO} (a more specific marker of interstitial lung disease) is consistent with no clinical cases having been recognized at this plant.

Flock workers at this plant are exposed not only to flock-associated dust, but also to paper dust. Paper dust itself results in higher prevalences of many symptoms as shown by comparing paper-exposed workers with ribbon workers. Paper dust may account for a proportion of mucous membrane irritation and airways symptoms (cough, phlegm, and wheeze), as well as airways hyperresponsiveness. However, paper dust is not known to be associated with restrictive lung disease, whereas flock-associated dust exposure is associated with the restrictive disease of flock workers' lung. Indices of mild restrictive lung disease at this

TABLE VI. Adjusted Means for Forced Expiratory Volume in One Second (FEV_1), Forced Vital Capacity (FVC), and FEV_1/FVC for Strata of Gender, Smoking, and Flock-Work

	Flock work		
Outcome/gender	**<1 hr/week**	**≥1 hr/week**	**Difference**
FEV_1 means			
Females/never smokers	2.890	2.950	+0.060 L
Females/ever smokers	2.880	2.921	+0.041 L
Males/never smokers	3.524	3.637	+0.113 L
Males/ever smokers	3.814	3.389	−0.425 L*
FVC means			
Females/never smokers	3.547	3.674	+0.127 L
Females/ever smokers	3.600	3.608	+0.008 L
Males/never smokers	4.484	4.506	+0.022 L
Males/ever smokers	4.927	4.398	−0.529 L*
FEV_1/FVC means			
Females/never smokers	81.8	80.7	−1.1
Females/ever smokers	79.8	81.0	+1.2
Males/never smokers	79.2	80.9	+1.7
Males/ever smokers	77.7	77.5	−0.2

*P-value <0.05.
Means have been adjusted for the body mass index (BMI), height, age, tenure, and race.

plant are elevated in flock workers, in workers who clean equipment with compressed air at least 1 hr per week, and in workers who have worked with flock for a period of 5 years or more. These health outcomes may reflect higher flock-associated dust exposures in the past and the long average period of employment of participants.

The typical findings of pulmonary function tests in interstitial diseases, such as flock workers' lung, are consistent with restrictive impairment. However, functional and pathologic alterations consistent with small airways disease have been described in patients with various interstitial pulmonary diseases, including interstitial pulmonary fibrosis [ATS, 2002]. Although not studied systematically before this study with methacholine challenge tests, the occurrence of airways hyperresponsiveness among flock-exposed workers may be implied by the presence of increased asthma-like symptoms in epidemiological studies [Washko et al., 2000; Daroowalla et al., 2005]. Bronchial hyperresponsiveness (a positive MCT) has been found in some patients with flock workers' lung [Kern et al., 2000]. We found that employees with abnormal MCT were four times more likely to have worked with flock for at least 1 hr per week than other workers. Nevertheless, the prevalence of asthma-like symptoms, such as wheezing and chest tightness, was not increased in flock workers at this factory. It is possible that this reflects a so-called ''healthy-worker effect'' commonly observed in cross-sectional occupational disease studies. Nevertheless, we are not aware of workers who left employment due to respiratory disease. Paper dust, regardless of the presence of flock dust, could be responsible for the observed airways hyperresponsiveness among employees at this plant. Torén et al. [1994] reported an increased risk for respiratory symptoms among workers exposed to paper dust.

This workplace survey has the usual limitations of an observational study. The relatively small number of flock-exposed workers makes it difficult to perform more sophisticated statistical analyses that would take into account the influence of other possible variables on the associations between exposure and health effects. Misclassification of current and historical exposures may have occurred in using questionnaire responses. In addition, different work processes could be associated with the same job title or job department, which in part may explain the differences observed between males and females. For example, about 140 workers were classified as being involved in some type of machine operation, but it may be relevant to know whether the operations primarily involved cutting, application, gluing, folding, and so on. Future work may need to focus more on determining the most common specific daily tasks for each worker within a plant rather than relying on a general knowledge of job and department categories. Another limitation is the use of tenure and work processes and practices as markers of exposure. However, the low levels of flock-associated dust found during our environmental sampling, prevented the development of a job-exposure matrix. Longer duration sampling would be necessary to quantify exposures above the limits of detection. Even longer duration sampling, however, would not address the possible importance of peak exposures, as suggested by compressed air cleaning being a risk factor for symptoms and diagnoses arising during employment. Finally, we did not perform chest radiographs given the lack of sensitivity of this test for detecting parenchymal abnormalities among flock workers [Washko et al., 2000].

Our findings contribute to concerns about the interstitial lung effects of diverse synthetic dusts—nylon, polyethylene, polypropylene, and now rayon. For none of these substances do past studies document levels of exposure that are health-protective. Work practices resulting in short-term high exposures, such as the use of compressed air for cleaning, appear associated with respiratory outcomes in three studies. Quantitative characterization of such exposures is difficult, and elimination of particulate dispersing practices and equipment is prudent. This industry provides another example of an unregulated particulate being found to be hazardous at extremely low average levels compared to current dust permissible exposure limits. Inhalation toxicological studies in animal models would be useful to evaluate relative toxicity of synthetic dusts, so that material substitution could be considered in addition to engineering controls and respiratory protection. Since we were not able to define the individual contribution of flock and paper in either mass or fiber measurements, additional studies of rayon flock production workers would also be useful to resolve residual questions regarding exposure-response relations.

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